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13. ABSTRACT (Maximum 200 words)
This research project was aimed at an investigation of far-infrared (FIR) and terahertz (THz) sources using intersubband transitions in step quantum well structures. Theoretical studies were carried out in order to determine the optical gain spectra. The intersubband gain was formulated as a function of the dipole matrix elements, the lineshape function, and the electron distribution functions in the lasing subbands. The dependence of the spectral gain on optical phonon scattering was investigated. Non-Lorentzian lineshape functions were obtained and it was found that the magnitude and overall shape of the spectral gain are significantly modified by the intra- and inter-subband phonon scattering rates. Effects of the confined phonon modes were evaluated and it was found that they have a significant effect on the devices considered.

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Final Report

Intersubband Lasers at Infrared and Terahertz Frequencies

Submitted to

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Intersubband Lasers at Infrared

and Terahertz Frequencies

July 1, 1998-June 30, 2000

1. Abstract:

This research project was concerned with a theoretical investigation of the properties of intersubband lasers for Far Infrared (FIR) and Terahertz (THz) frequencies. Theoretical models were developed to determine the optical gain spectra in various types of intersubband lasers including Quantum Cascade (QCL) and Step Quantum Well Lasers (SQL). The dependence of device properties on various material parameters and the effects of confined phonon modes were investigated. The results obtained from these studies will be very important in the design of lasers based on intersubband transitions.

2. Scientific Personnel:

Faculty Supervisor:	Prof. G. I. Haddad
Research Staff:	Dr. J. P. Sun
Graduate Students:	None

3. Specific Aim:

The specific aim of this project was to develop improved models for predicting spectral gain in intersubband lasers. This included a determination of phonon relaxation rates which are very important in determining the properties of such lasers. In particular, special consideration was given to the effects of confined phonon modes in quantum wells and their importance in determining basic device design and properties.

4. Significant Accomplishments:

- Modeling capability of various laser physical parameters was developed to establish a design capability for intersubband laser structures. The calculations based on these models included the electron states in intersubband laser structures, intersubband relaxation rates, tunneling injection and escape times, carrier population inversion, transition matrix elements, oscillator strength, lineshape functions, optical gain spectra, threshold current density, and output power. This is significant in designing optimum device schemes for FIR and THz lasers.

- We have also studied effects of rough heterointerfaces on the shape of the THz absorption peak in quantum well structures. The equation for intersubband polarization was considered in the resonant approximation, taking into account the depolarization shift. The lineshape of the intersubband absorption peak was formulated and calculated for the case with long range variations of heterointerfaces.

- The intersubband optical gain was formulated and calculated for two step quantum well laser structures under investigation. This is an important step in the design of optimum device schemes for FIR and THz lasers since the gain determines the laser threshold characteristics. It is calculated as a function of several critical device design parameters, including electron population inversion, distribution functions in the subbands, the lineshape function, temperature, and photon frequency.

- We have calculated non-Lorentzian lineshape functions for these laser structures depending on various intra- and inter-subband phonon scattering mechanisms. This is significant progress as compared to the usual adoption of the Lorentzian lineshapes which may lead to either an over-estimate or under-estimate of the optical gain. Moreover, the confined phonon effects, especially effects of the interface optical phonon scattering on the gain have been included, which can greatly modify the overall shape and magnitude of the gain. This will aid in the design of FIR and THz lasers.

- Our modeling capability has enabled us to study and conceive alternative device schemes for FIR and THz sources. We have investigated Quantum Cascade Lasers (QCL) and Step Quantum Well Lasers (SQL) which were conceived by us and may result in enhanced performance as compared to QC Lasers.

- The results of this investigation are given in detail in the following publications which are attached as part of this report.

5. Publications:

H. B. Teng, J. P. Sun, G. Haddad, M. Stroscio, S. Yu and K. Kim, "Phonon Assisted Intersubband Transitions in Step Quantum Well Structures," *J. Appl. Phys.*, **84**: 2155-2164, 1998.

M. A. Stroscio, "Quantum Cascade Lasers and Quantum Well Intersubband Lasers," a book chapter in *Advances in Semiconductor Lasers and Applications to Optoelectronics*, M. A. Stroscio and M. Dutta, eds., to be published,

F. T. Vasco, J. P. Sun, G. I. Haddad and V. V. Mitin, "Inhomogeneous Broadening of Intersubband Transitions Due to Nonscreening Roughness of Heterointerfaces," to appear in *J. Appl. Phys.*

6. Honors and Awards:

Prof. Haddad received the Third Millennium Medal from the IEEE-Microwave Theory and Techniques Society for his significant contributions to the profession.